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Remotely operated subsea inspection vehicle - has astable pressure vessel with DC brushless motor-driven thrusters to achieve six degrees of freedom

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EP 359799	A	19900328	EP 89903191	A	19890203		199013
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Abstract (Basic): WO 8907071 A

Vehicle comprises an astable cylindrical aluminium pressure vessel (1) with detachable domed stern end cap (12). Services are provided via the umbilical tether (13) at the main lift point (9). External fittings include an hydraulic pack (7), video cameras (2), valve pack (3) and three multi-segment manipulator arms (19) equipped with a tool or tool table (20).

Arcuate buoyancy tanks (8) are arranged in opposition to each other so as almost to surround the tubular body (10). Ten, brushless DC motor driven thrusters arranged as an aft pair (16) and two groups of four, circumferentially mounted, (18) enable movement in all six degrees of freedom allowed by the astable configuration. The vessel can be moved in any direction, at any attitude of pitch, roll or yaw, emulating the flexibility of a diver.

USE/ADVANTAGE - Also for cleaning of under sea structures. Is highly manoeuvrable and has flexibility of a diver.

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Title Terms: REMOTE; OPERATE; SUBSEA; INSPECT; VEHICLE; ASTABLE; PRESSURE; VESSEL; DC; BRUSH; MOTOR; DRIVE; THRUSTER; ACHIEVE; SIX; DEGREE; FREE

Derwent Class: Q24; W06

International Patent Class (Additional): B63C-011/42; B63G-008/00

File Segment: EPI; EngPI

A subsea inspection vehicle which is intended to be remotely operated comprises a substantially cylindrical pressure vessel (1). A pair of generally arcuate buoyancy tanks (8) and external equipment (3, 7) are supported on the vessel (1) in a manner arranged such that the vessel remains substantially astable. A plurality of thrusters (16, 18) are carried by the vessel (1) and are arranged to enable movement of the vessel (1) relative to all six degrees of freedom provided by its astable configuration. The vessel can be moved in any direction at any attitude of pitch, roll or yaw and can thereby emulate the flexibility of movement of a diver.

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A SUBSEA VEHICLE.

05 The present invention relates to a subsea
vehicle and to a method of working on an underwater
work site using such a vehicle.

10 Presently, a number of routine underwater tasks
are performed by remotely operated vehicles. However,
such vehicles cannot emulate the flexibility of
movement of a diver and accordingly, more advanced
and sophisticated tasks underwater still have to be
undertaken by divers.

15 It is an object of the present invention to
provide a subsea vehicle having more flexibility of
movement than known vehicles.

20 According to a first aspect of the present
invention there is provided a subsea vehicle
comprising a pressure vessel, and drive means
supported by said pressure vessel for causing movement
thereof, wherein said pressure vessel is arranged to
be substantially astable, and said drive means are
arranged to enable movement of said pressure vessel
25 relative to six degrees of freedom.

30 Thus, the pressure vessel is displaceable
in translational directions whose components can be
defined in three orthogonal dimensions. Furthermore,
the pressure vessel is also movable in angular
directions whose components can be defined by a set of
spherical co-ordinates.

35 The six degrees of freedom capability of the

pressure vessel enables the pressure vessel to be moved in any direction at any attitude of pitch, roll or yaw.

05 Because the vehicle is able to achieve a full six degrees of freedom of movement it is able to emulate a diver and therefore is more flexible than prior art vehicles.

10 In an embodiment the astable pressure vessel is arranged to be able to roll through $\pm 180^\circ$ and to pitch through $\pm 90^\circ$. Preferably, the vessel has the ability to roll through 360 degrees.

15 Preferably, the pressure vessel is substantially cylindrical. Electrical and electronic systems of the vehicle can be mounted within the pressure vessel.

20 Preferably, the drive means comprise a plurality of individual thrusters supported by the pressure vessel and arranged to provide movement thereof in the six degrees of freedom.

25 Whilst it would be possible to mount the thrusters to be pivotable or otherwise displaceable to different orientations, it is preferred that the thrusters should all be fixed in their alignment such that it is reliably ensured that movement relative to all of the six degrees of freedom is provided for.

30 In a preferred embodiment at least six thrusters are supported on the pressure vessel. Two of these thrusters are mounted on an end surface of the pressure vessel on a transverse axis of the pressure

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vessel. Preferably, these two end thrusters are equidistantly spaced on either side of the central longitudinal axis of the vessel at the aft end. Preferably, each end thruster is inclined at an angle to said transverse axis, for example, of substantially 30 degrees.

The other four thrusters, are mounted circumferentially of the pressure vessel. Preferably, these thrusters are equidistantly spaced around the circumference of the pressure vessel at a single longitudinal location of the vessel. In this embodiment, each of the circumferentially mounted thrusters is located on a radius of the vessel extending substantially at 45 degrees to the transverse axis thereof. Alternate ones of these thrusters face in opposite directions.

In a preferred embodiment two groups of four circumferentially arranged thrusters are provided, each group being located at opposite ends of the cylindrical pressure vessel. Thus, at least ten thrusters in all are provided.

Generally, the two aft thrusters provide longitudinal thrust forward and aft and give the pressure vessel a degree of yaw capability. The circumferentially mounted thrusters can be used in different combinations for rolling and pitching the pressure vessel and to translate the pressure vessel both transversely and along a third axis, which is generally vertical, which is orthogonal to both the longitudinal and transverse axes of the pressure vessel.

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05 Preferably, the pressure vessel supports one or more manipulators. Where thrusters are supported at the aft end of the pressure vessel, it is particularly suitable for the or each manipulator to be supported at the forward end of the pressure vessel.

10 The number, type, and method of control of the manipulators may be chosen as required. However, it is particularly useful if at least two manipulators are provided which are moveable, at least in some dimensions, relative to one another.

15 Generally, the pressure vessel supports buoyancy tanks arranged to give the vehicle the required buoyancy and the required centre of buoyancy. The position and volume of these tanks is chosen in dependence upon the weight and position of the equipment to be supported on said pressure vessel. Preferably, a pair of generally arcuate buoyancy tanks are arranged around the circumference of the pressure vessel substantially opposite to one another. In addition, the manipulators and other equipment may be supported on the pressure vessel by appropriate buoyancy tanks forming support frames therefor.

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30 The ancillary equipment carried by the pressure vessel may comprise two spaced video cameras which are mounted on a fixed and known baseline. For example, the two video cameras may be mounted on the transverse axis of the pressure vessel at the forward end thereof. A controller, for example, incorporating a microprocessor, can be provided for driving pan and tilt units for these video cameras, with their position and their movement being described by an

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appropriate set of co-ordinates. It is also proposed to describe the manipulator positions and movement by way of the same co-ordinate system and to couple a control system for the manipulators to the camera controller. This makes it possible to drive the video cameras to follow the manipulators as they travel. Furthermore, by focusing both of the cameras on a single point, the location of this point can be accurately described and thus the movement of part of one or more manipulators accurately to that point can be simply achieved. Preferably, the position and movement of the cameras and manipulators is defined by a set of orthogonal co-ordinates.

The present invention also extends to a control system for at least one manipulator comprising manipulator control means for controlling movement of the manipulator and for receiving information as to the position of the manipulator, at least two sight means positioned on a common baseline, means for adjusting the orientation of the sight means, and control means for controlling said adjusting means and for receiving information as to the orientation of the sight means, wherein said manipulator control means and said control means for the sight means are arranged to communicate.

Preferably, said manipulator control means and the control means for the sight means are coupled such that information as to the position of the manipulators can be fed to the control means for the sight means, and conversely, so that information as to the orientation of the sight means is receivable by said manipulator control means.

Preferably, and as described above, the position information in respect of the manipulators and the orientation information in respect of the sight means is described using the same system of orthogonal co-ordinates. As described above, said sight means are preferably video cameras.

According to a further aspect of the present invention there is provided a method of working on an underwater work site using a remotely operated subsea vehicle, comprising orientating the vehicle near the work site in an upright attitude relative to the work site with a forward end of the vehicle facing the work site and then performing tasks at the work site by way of equipment carried at the forward end of the vehicle.

Preferably, the vehicle is movable relative to six degrees of freedom so that it can be orientated in an upright attitude relative to the work site irrespective of the orientation of the work site.

Preferably, the vehicle is provided with attachment means for attaching the vehicle in its upright attitude to a support surface. The attachment means may enable the vehicle to be translated and/or rolled relative to said support surface.

According to a still further aspect of the present invention there is provided a subsea vehicle having drive means arranged to enable movement of said vehicle in angular directions whose components can be defined by a set of spherical co-ordinates, and processor means for controlling the drive means,

wherein, said vehicle is also provided with sensing means for determining the angular attitude of the vehicle, said processor means being responsive to said sensing means.

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In an embodiment, said sensing means supplies data to the processor means representative of the roll angle and the pitch angle of the vehicle. The processor means may also be provided with data representative of the rate of change of the yaw angle of the vehicle.

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In a preferred embodiment, a depth sensor is mounted on said vehicle and is arranged to supply information to said processor means. The depth sensor is preferably a pressure transducer mounted close to the roll centre of the vehicle.

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Said processor means is also arranged to be responsive to demands made by an operator.

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Preferably, and as defined above, said drive means comprise a plurality of individual thrusters controlled by said processor means. Furthermore, and again as defined above, the vehicle is preferably comprised of a substantially astable pressure vessel on which the drive means are supported to enable movement of said pressure vessel relative to six degrees of freedom.

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Embodiments of the present invention will hereinafter be described, by way of example, with reference to the accompanying drawings, in which:

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Figure 1 shows schematically a perspective view of a remotely operated subsea vehicle,

05 Figure 2 shows a side view of the vehicle of Figure 1,

Figure 3 shows a front end view of the vehicle of Figures 1 and 2 with the manipulators removed, and partially with other equipment removed,

10 Figures 4a and 4b show respectively an aft end view and a side view of the vehicle of Figure 1, the vehicle being indicated in outline only to illustrate the positioning of thrusters,

15 Figure 5 shows an underwater structure and schematically indicates different orientations taken up by said vehicle for access to different work sites, and

20 Figure 6 shows schematically a control system for a subsea vehicle.

25 Figure 1 shows schematically a perspective view of a subsea inspection vehicle which is intended to be remotely operated. This vehicle is specifically designed for use underwater to clean and inspect subsea structures. A side view of the vehicle is shown in Figure 2, whilst Figure 3 shows a view of the front of the vehicle with its manipulators removed, and partially with other equipment removed, for clarity.

30 It will be seen from Figures 1 to 3 that the

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vehicle comprises a substantially cylindrical pressure vessel 1, for example, formed of aluminium. This pressure vessel 1 has a tubular body 10 to which a forward domed end cap 11 is permanently fixed, and
05 having a detachable domed stern end cap 12. Substantially centrally of the longitudinal extent of the tubular 10, the pressure vessel 1 is provided with a main lift point 9 to which an umbilical tether 13, for supplying services, is arranged to be connected.
10 Other fittings may be provided externally of the pressure vessel 1 to carry ancillary components, such as an hydraulic pack 7, a pair of video cameras 2, and a valve pack 3. Additional equipment (not shown) for the vehicle is mounted within the pressure vessel 1.
15 For example, this equipment may include a transformer unit and a rack-mounted electrical system for the vehicle. These internal components are not illustrated in the drawings for clarity.

20 A pair of buoyancy tanks 8 are mounted on the pressure vessel 1 externally thereof. In the embodiment illustrated, these buoyancy tanks 8 are each generally arcuate in shape and are arranged opposed to one another such that they substantially
25 surround the tubular body 10 except for two longitudinally extending spaces in which the valve pack 3 and the hydraulic pack 7 are received. Thus, the periphery of the vehicle carrying the buoyancy tanks 8 and the packs 3 and 7 remains substantially
30 cylindrical.

Because the pressure vessel is cylindrical it is generally astable, and it will be appreciated that the external equipment, as 3, 7, and the buoyancy tanks 8
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are supported thereon in a manner arranged to maintain the astable characteristics required.

05 The pressure vessel 1 carries drive means in the
form of a plurality of thrusters 16 and 18 which are
arranged to enable movement of the vessel relative to
all six degrees of freedom provided by the astable
configuration. In the embodiment illustrated, ten
thrusters 16, 18 in all are supported on the pressure
10 vessel, and are arranged as two aft thrusters 16
and two groups of four circumferentially mounted
thrusters 18.

15 The relative orientation of the thrusters 16, 18
can most clearly be seen in Figures 4a and 4b which
respectively indicate a stern elevation and a side
elevation of the vehicle, the vessel 1 being outlined
in dotted lines whilst the outlines of the thrusters
16, 18 are shown in full lines. It will be apparent
20 from Figure 4a that the two aft thrusters 16 are
mounted at either side on the aft end of the tubular
body 10 on a transverse axis A-A thereof. These two
thrusters 16 extend and converge in the longitudinal
direction of the vessel 1 and each is at an angle of
25 30 degrees relative to the transverse axis A-A. These
two thrusters 16 can be controlled to move the vessel
forward and aft, that is, substantially in the
direction of its longitudinal axis B-B. In addition,
the two thrusters 16 can be controlled to give yaw
30 capability to the vessel, that is, to provide movement
in the transverse plane relative to the longitudinal
axis B-B.

35 The thrusters 18 are arranged in two groups of

four, circumferentially mounted about the fore and aft ends of the tubular body 10 of the vessel 1. The four circumferentially mounted thrusters 18 at each longitudinal location are equidistantly spaced around the circumference. It will be appreciated that each thruster 18 extends substantially parallel to a tangent to the cylindrical pressure body 10 and is located on a radius thereof extending at 45 degrees to the transverse axis A-A and hence to the third orthogonal axis C-C of the vessel 1. It will also be appreciated that alternate ones of the thrusters at each longitudinal location face in opposite directions. The arrangement of the eight thrusters 18 is such as to enable different combinations of the thrusters to be used to cause rolling of the pressure vessel around its longitudinal axis B-B, and pitching of the vessel about the third axis C-C, which is shown to extend vertically. In addition, the thrusters 18 can be used to translate the vessel along the third axis C-C and also transversely along the transverse axis A-A. Of course, combinations of all of these movements can be achieved.

The number, positioning and relative orientation of the thrusters 16, 18 can be chosen as required to suit the characteristics of any particular vehicle. Similarly, the thrusters or other alternative drive means may be of any required design suitable for use underwater.

In a preferred embodiment, the thrusters 16 and 18 incorporate brushless DC motors because such motors are particularly energy efficient, are reliable, and have the added advantage of being able to produce more

power from a small package.

05 A number of manipulator arms 19 are carried at
the forward end of the pressure vessel 1. In the
embodiment illustrated, three manipulator arms 19 are
provided, the central arm being supported by the
forward end cap 11 of the pressure vessel 1 by way of
a support frame 15 and the two outer manipulator arms
being supported on the end cap 11 by way of respective
10 support frames 14. Again, the number, method of
support, type of manipulator and control means
therefor may be chosen as required.

15 Preferably, and as illustrated, the support
frames 14 and 15 are constructed as buoyancy tanks
which can be trimmed to provide the vessel 1 with a
suitable centre of buoyancy depending upon the weight
and positioning of the manipulator arms 19 and of
any other equipment supported on the pressure vessel
20 1.

The three manipulators 19 illustrated in the
drawings are substantially conventional
multi-segment arms, each segment being pivotally
25 connected to the next, with at least two of the pivot
axes of each arm extending substantially orthogonally
to provide maximum freedom of movement for that arm.
In addition, at its free end, each manipulator 19 is
equipped with a tool or tool table 20 which is
30 rotatable through 270 degrees.

In the embodiment illustrated, the manipulator
arms 19 are moved as required by hydraulic power
supplied from the hydraulic pack 7 and controlled by
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solenoid valves (not shown) of the valve pack 3.

05 Movement of the manipulator arms 19 is under the
control of a manipulator control system (not shown)
provided at the surface and connected to the valve
pack 3 by way of the umbilical tether 13. It will be
appreciated that any suitable control system for the
manipulators 19 may be provided, but preferably, the
control system incorporates a microprocessor. In one
10 preferred embodiment, the control system incorporates
master arms, each corresponding to a respective
individual manipulator, which allows the operator on
the surface a degree of "feel" in operating the
manipulator arms.

15 Preferably, the manipulator arms are controlled
using a Cartesian or other orthogonal co-ordinate
system. Thus, the x, y and z co-ordinates of each
tool carried by a manipulator can be calculated by
20 measuring each joint angle, for example by way of
potentiometers at the joint of each manipulator, and
by storing accurate information as to the geometry of
each manipulator arm. In this way, if a tool of a
manipulator is working on a defect, the exact position
25 of the manipulator tool can be calculated whereby
the position of that defect can be determined.

To maintain accuracy, each manipulator will have
at least one reference position on the vehicle to
30 which it can be returned as required such that the
control system for the manipulators can be
re-calibrated. These reference positions are
generally the rest positions of the manipulators.

05 The use of an orthogonal co-ordinate system for
the manipulator control system enables the operator to
perform tasks very accurately. For example, before
undertaking a cleaning or inspection operation, the
operator can cause the tool of each manipulator to
premeasure its route by touching a number of points
along the route it will need to take. These points
will each be described in orthogonal co-ordinates and
interpreted by way of the processor of the manipulator
control system to create a single curve along which
the manipulator arm will then be controlled to move.
If necessary, vertical or horizontal offsets can be
pre-set to avoid damage to instruments, for example,
carried by the manipulators, and limits can be pre-set
to prevent the operator from exceeding those offsets.
For example, when cleaning a structure using high
pressure water from cavitation jets, this system can
prevent loss of cleaning effectiveness caused by
positoning the jet either too close or too far away
from the surface being cleaned.

25 Data as to the position of the manipulators and
their tools is continually fed back to the surface
enabling the position and extent of the defects and
other items of interest on the structure being
inspected to be determined. This manipulator
positional data is integrated with vehicle positional
data, giving the roll, pitch and heading of the
vehicle as will be described hereinafter, so that the
absolute position of any point touched by the tool of
one of the manipulators can be calculated with a high
degree of accuracy.

35 It will be appreciated that the operator on the
surface needs to "see" the structure being inspected

05 or worked upon. In this respect, one or more of the manipulators 19 may carry a video camera as 21. Light sources, as 22, are provided on the forward end of the vehicle and may also be carried by the manipulators if necessary.

10 As made clear previously, the forward end of the pressure vessel 1 additionally carries a spaced pair of video cameras 2, which are preferably mounted at either side of the cylindrical body of the pressure vessel on the transverse axis thereof, which defines a fixed, common baseline. Each of these video cameras 2 is mounted by way of a pan and tilt unit, indicated at 15 23, for enabling the orientation of the camera to be selectively adjusted. Again, a control system (not shown) for the pan and tilt units 23 incorporating processor means is provided, preferably on the surface. The processor means of the pan and tilt unit control system uses the same co-ordinate system as 20 used by the manipulator control system, and the two control systems are arranged to communicate. The pan and tilt units for the cameras 2 are provided with position feedback potentiometers (not shown) to give to the control system information as to the 25 orientation of the video cameras 2.

30 Because the control systems for the cameras 2 and for the manipulators 19 communicate, it is possible for the software of the manipulator control system to determine the position of a manipulator tool and then for the control system for the cameras to cause 35 movement of the cameras 2, by way of their pan and tilt units 23, to a correct position to view the manipulator tool.

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05 The communicating control systems for the pair of
cameras 2 and the manipulators 19 also make it
possible to determine the position of a point or
object by use of the video cameras. Each camera is
10 provided with bore sights, for example cross-hairs on
the lens or an electronically produced crosswire, and
the operator then drives the cameras to line up on the
target, that is to both be aligned on the same point.
By calculating the x and y angles of each camera
15 relative to the vehicle and by comparing these angles
for the two cameras 2 on the common baseline, the
software of the control system for the cameras is able
to calculate the position of the target. If this
information is then fed to the manipulator control
20 system, one of the manipulators can be driven to the
appropriate position.

20 The vehicle illustrated in Figures 1 to 4 is
additionally provided with an attachment system,
generally referenced 25. Generally, this attachment
system comprises two plates 26 each pivotably mounted on
a tubular member (not shown) slidably received within a
body member 27. Means (not shown) are provided to
advance the tubular member, and hence the plates 26,
25 longitudinally relative to the body member 27.
Conveniently, the advancing means comprises a thruster
(not shown) housed within the body member 27. In
addition, hydraulic rams (not shown) are provided to
30 position each plate 26 at a predetermined angle relative
to the body member 27 and to maintain the plates in
position. It will be appreciated that each plate 26 can
thereby be clamped into position on a structural member,
such as the tubular structural member 30 illustrated.

When the plates 26 of the attachment device 25 are so clamped onto the structural member 30, movement of the vehicle away from the structural member 30 is prevented. However, contact between each plate 26 and the support member 30 is preferably by way of one or more castors (not illustrated) mounted on the contact surface of the plate 25. By this means, movement of the vehicle along the structural member and/or around the member 30 is enabled.

The manner in which the vehicle would normally be used at a work site is schematically illustrated in Figure 5. In this respect, Figure 5 shows an underwater structure made from a number of interconnected tubular members 30. Commonly it is required to clean and inspect the welds of such a structure, the welds occurring at each area where two of the tubular members are joined.

In the position marked A in Figure 5, the vehicle is arranged in its upright position in which the pressure vessel 1 exhibits zero degrees of roll about its longitudinal axis B-B and zero degrees of pitch. The tubular member 30 to which the vehicle is attached, by way of the attachment system 25, extends substantially horizontally. It will be seen that in position A of the vehicle, the node N to be cleaned and inspected is substantially directly in front of the vehicle.

In position B, whilst the vessel 1 still has a zero degree roll angle, it has been moved through a pitch angle of 45 degrees. Again, in this position it will be seen that the work site is again directly in front of the vehicle.

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In position C, the pitch angle of the vessel is zero degrees, but it has been rolled through 180 degrees. In position D, the pitch angle is - 90 degrees and the roll angle is zero.

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It will be appreciated that in each of the positions A, B, C and D, illustrated in Figure 5 the work site is directly in front of the vehicle. Furthermore, the whole length of the support member 30 to which the vehicle is attached can be inspected simply by translating the vehicle therealong whilst still attached. This enables effective and efficient use to be made of relatively simple manipulator arrangements with consequent reliability. Furthermore, regardless of the angle at which the support member extends, the vehicle once affixed thereto can roll around the tubular member.

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As is described above, the vehicle is driven by the thrusters 16, 18 which are controlled by a central processor unit, as 50, Figure 6. This processor unit 50 is arranged to determine how much thrust each of the thrusters should apply to achieve the attitude required. In this respect, and as shown in Figure 6 the following information is utilised by the processor 50 to enable it to determine the power distribution to the thrusters:

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1. Roll angle.
2. Pitch angle.
3. Rate of change of yaw angle.
4. Depth.
5. Operator Demand.

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In addition, information as to the current centre

of buoyancy and centre of gravity of the vehicle is fed to the processor 50 by way of a line 60 on manual initialisation. This initialisation process is performed manually in order to allow for any changes in pay load of the vehicle. It will be seen that the line 60 is connected to a control panel 76 for enabling other operator demands or information to be input to the processor 50.

The depth information is obtained by way of a depth sensor, schematically represented at 62, which is preferably a pressure transducer, mounted on the vehicle forwardly thereof as near to the longitudinal axis B-B of the pressure vessel 1 as possible. The output of the depth sensor 62 is first fed to register means 54, which also receives data from roll sensor means 64 and pitch angle sensor means 66. The data as to the vehicle's roll angle and pitch angle received by the register means 54 is, of course, representative of the attitude of the vehicle. A computation is performed in the register means 54, by way of an appropriate software sub-routine, to adjust the depth information in accordance with the attitude data. By this means, the depth data is representative of the depth beneath the vehicle irrespective of its attitude.

The roll sensor means 64 and pitch angle sensor means 66 are incorporated in a vertical reference unit (not illustrated) which is fitted within the pressure vessel 1 at or about the centre of buoyancy of the vehicle. This is generally at a position slightly forward of the centre point of the pressure vessel 1. For example, the sensor means 64 and 66 may be

constituted by the gyroscope of a standard vertical reference unit arranged to provide signals representative of the pitch angle and roll angle of the vessel. In addition, a yaw rate gyro, represented at 68, is arranged to supply information as to the rate of change of the yaw angle. The yaw rate gyro 68 is also housed within the vessel 1.

The adjusted depth data output from the register means 54, and the data as to roll angle, pitch angle, and yaw angle of the vehicle, is fed to an integrator 56 where the rates of change of the sensed data are computed. The data and the rate of change data is then presented by way of a convertor 58, which converts the data into orthogonal co-ordinates, to the central processor 50.

Figure 6 also indicates that attitude and position demands made for the vehicle, either automatically by way of an auto controller 70, or by way of an operator, using a joystick operated control means 72, are fed to the processor 50. These demands are presented to the processor 50 by way of a convertor 58 which converts the data into orthogonal co-ordinates. It will be appreciated that the processor 50 compares the demands made, either automatically or by way of the operator, with the data obtained from the sensors and determines therefrom the demands to make on the thrusters 16, 18 of the vehicle. A pre-programmed database of thruster geometry and the power sharing of the thrusters provides information to enable the processor 50 to determine which thrusters to activate and how much thrust from each thruster is required. The processor

05 50 then sends appropriate control signals to thruster control units 52. As will be seen in Figure 6, a single thruster control unit 52, is associated with each thruster, and the thruster control units 52 are arranged to supply to the central processor 50 data as to the power supply and speed of rotation of their associated thrusters.

10 In the embodiment illustrated, the central processor 50 is also arranged to constitute the control means for the video cameras 2. In this respect, the processor 50 is arranged to send appropriate control signals to a control unit 78 for
15 the pan and tilt units 23 of the cameras 2. Information from the pan and tilt units as to the orientation of the cameras 2 is also fed to the processor 50.

20 It will be appreciated that other inputs to and outputs from the processor 50 may be made if required. For example, the processor 50 may constitute the control means for the manipulators 19 and may be arranged to provide control signals to drive units
25 therefor and to receive information therefrom. This is illustrated in Figure 6 by the further interfaces 80.

30 It will be appreciated that variations in and modifications to the vehicle as described above may be made within the scope of the present invention.

CLAIMS

- 05 1. A subsea vehicle comprising a pressure vessel, and drive means supported by said pressure vessel for causing movement thereof, wherein said pressure vessel is arranged to be substantially astable, and said drive means are arranged to enable movement of said pressure vessel relative to six degrees of freedom.
- 10 2. A subsea vehicle as claimed in Claim 1, wherein said drive means are arranged to enable displacement of said pressure vessel in translational directions whose components can be defined in three orthogonal dimensions, and to enable movement of the pressure
15 vessel in angular directions whose components can be defined by a set of spherical co-ordinates.
- 20 3. A subsea vehicle as claimed in Claim 1 or 2, wherein said astable pressure vessel is arranged to be able to roll through $\pm 180^\circ$ and to pitch through $\pm 90^\circ$.
- 25 4. A subsea vehicle as claimed in Claim 3, wherein the pressure vessel has the ability to roll through 360 degrees.
- 30 5. A subsea vehicle as claimed in any preceding claim, wherein the pressure vessel is substantially cylindrical.
6. A subsea vehicle as claimed in any preceding claim, wherein electrical and electronic systems of the vehicle are mounted within the pressure vessel.
- 35 7. A subsea vehicle as claimed in any preceding claim, wherein the drive means comprise a plurality of individual thrusters supported by the pressure vessel

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and arranged to provide movement thereof in the six degrees of freedom.

05 8. A subsea vehicle as claimed in Claim 7, wherein the thrusters are all mounted in a fixed, predetermined alignment.

9. A subsea vehicle as claimed in Claim 7 or 8, wherein at least six thrusters are supported on the pressure vessel.

10. A subsea vehicle as claimed in any of Claims 7 to 9, wherein two thrusters are mounted on an end surface of the pressure vessel on a transverse axis of the pressure vessel.

11. A subsea vehicle as claimed in Claim 10, wherein said two end thrusters are equidistantly spaced on either side of the central longitudinal axis of the vessel at the aft end.

12. A subsea vehicle as claimed in Claims 10 or 11, wherein each said end thruster is inclined at an angle to said transverse axis.

13. A subsea vehicle as claimed in Claim 12, wherein said two end thrusters are each inclined at an angle of substantially 30 degrees to said transverse axis.

14. A subsea vehicle as claimed in any of Claims 7 to 13, further comprising four thrusters mounted circumferentially of the pressure vessel, said circumferentially mounted thrusters being equidistantly spaced around the circumference of the pressure vessel at a single longitudinal location of the vessel.

- 05 15. A subsea vehicle as claimed in Claim 14, wherein each of the circumferentially mounted thrusters is located on a radius of the vessel extending substantially at 45 degrees to the transverse axis thereof.
- 10 16. A subsea vehicle as claimed in Claim 14 or 15, wherein alternative ones of said circumferentially mounted thrusters face in opposite directions.
- 15 17. A subsea vehicle as claimed in any of Claims 7 to 16, wherein two groups of four circumferentially arranged thrusters are provided, each group being located at opposite ends of the cylindrical pressure vessel.
- 20 18. A subsea vehicle as claimed in any of Claims 7 to 17, wherein the pressure vessel supports one or more manipulators.
- 25 19. A subsea vehicle as claimed in Claim 18, having thrusters supported at the aft end of the pressure vessel, and wherein the or each manipulator is supported at the forward end of the pressure vessel.
- 30 20. A subsea vehicle as claimed in Claim 18 or 19, wherein at least two manipulators are provided and are moveable, at least in some dimensions, relative to one another.
- 35 21. A subsea vehicle as claimed in any preceding claim, wherein the pressure vessel supports buoyancy tanks arranged to give the vehicle the required buoyancy and the required centre of buoyancy.

- 05 22. A subsea vehicle as claimed in Claim 21, wherein a pair of buoyancy tanks are arranged around the perimeter of the pressure vessel substantially opposite to one another.
23. A subsea vehicle as claimed in Claim 22, wherein said pressure vessel is substantially cylindrical and said buoyancy tanks are generally arcuate .
- 10 24. A subsea vehicle as claimed in any preceding claim, wherein manipulators and other equipment is supported on the pressure vessel by way of buoyancy tanks which form support frames therefor.
- 15 25. A subsea vehicle as claimed in any preceding claim, wherein the pressure vessel carries two spaced video cameras which are mounted on a fixed and known baseline.
- 20 26. A control system for at least one manipulator comprising manipulator control means for controlling movement of the manipulator and for receiving information as to the position of the manipulator, at least two sight means positioned on a common baseline, 25 means for adjusting the orientation of the sight means, and control means for controlling said adjusting means and for receiving information as to the orientation of the sight means, wherein said manipulator control means and said control means for the sight means are arranged 30 to communicate.
- 35 27. A control system as claimed in Claim 26, wherein said manipulator control means and the control means for the sight means are coupled such that information as to the position of the manipulators can be fed to the control means for the sight means, and conversely, so

that information as to the orientation of the sight means is receivable by said manipulator control means.

- 05 28. A control system as claimed in Claim 26 or 27, wherein the position and movement of the manipulators and the orientation information in respect of the sight means is described using the same system of orthogonal co-ordinates.
- 10 29. A control system as claimed in any of Claims 26 to 28, wherein said sight means are video cameras.
- 15 30. A control system as claimed in any of Claims 26 to 29, comprises two video cameras mounted on a transverse axis of a subsea vehicle, wherein said control means for the sight means is arranged to drive pan and tilt units arranged to adjust the orientation of said video cameras, and wherein one or more manipulators are supported by said subsea vehicle.
- 20 31. A control system as claimed in Claim 30, wherein said subsea vehicle is as claimed in any of Claims 1 to 25.
- 25 32. A method of working on an underwater work site using a remotely operated subsea vehicle, comprising orientating the vehicle near the work site in an upright attitude relative to the work site with a forward end of the vehicle facing the work site and then performing
- 30 tasks at the work site by way of equipment carried at the forward end of the vehicle.
- 35 33. A method as claimed in Claim 32, wherein said vehicle is movable relative to six degrees of freedom so that it can be orientated in an upright attitude relative to the work site irrespective of the

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orientation of the work site.

05 34. A method as claimed in Claim 32 or 33, wherein said vehicle is provided with attachment means for attaching the vehicle in its upright attitude to a support surface.

10 35. A method as claimed in Claim 34, wherein the attachment means are arranged to enable the vehicle to be translated and/or rolled relative to said support surface.

15 36. A subsea vehicle having drive means arranged to enable movement of said vehicle in angular directions whose components can be defined by a set of spherical co-ordinates, and processor means for controlling the drive means, wherein, said vehicle is also provided with sensing means for determining the angular attitude of the vehicle, said processor means being responsive to
20 said sensing means.

25 37. A subsea vehicle as claimed in Claim 36, wherein said sensing means is arranged to supply data to the processor means representative of the roll angle and the pitch angle of the vehicle.

30 38. A subsea vehicle as claimed in Claim 36 or 37, further comprising means for supplying to said processor means data representative of the rate of change of the yaw angle of the vehicle.

35 39. A subsea vehicle as claimed in any of Claims 36 to 38, wherein a depth sensor is mounted on said vehicle and is arranged to supply information to said processor means.

40. A subsea vehicle as claimed in Claim 39, wherein the depth sensor is preferably a pressure transducer mounted close to the roll centre of the vehicle.

05 41. A subsea vehicle as claimed in any of Claims 36 to 40, wherein said processor means is arranged to be responsive to demands made by an operator.

10 42. A subsea vehicle as claimed in any of Claims 36 to 41, wherein said drive means comprise a plurality of individual thrusters controlled by said processor means.

15 43. A subsea vehicle as claimed in any of Claims 36 to 42, wherein said vehicle comprises a substantially .
astable pressure vessel on which the drive means are supported to enable movement of said pressure vessel relative to six degrees of freedom.

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FIG. 1.

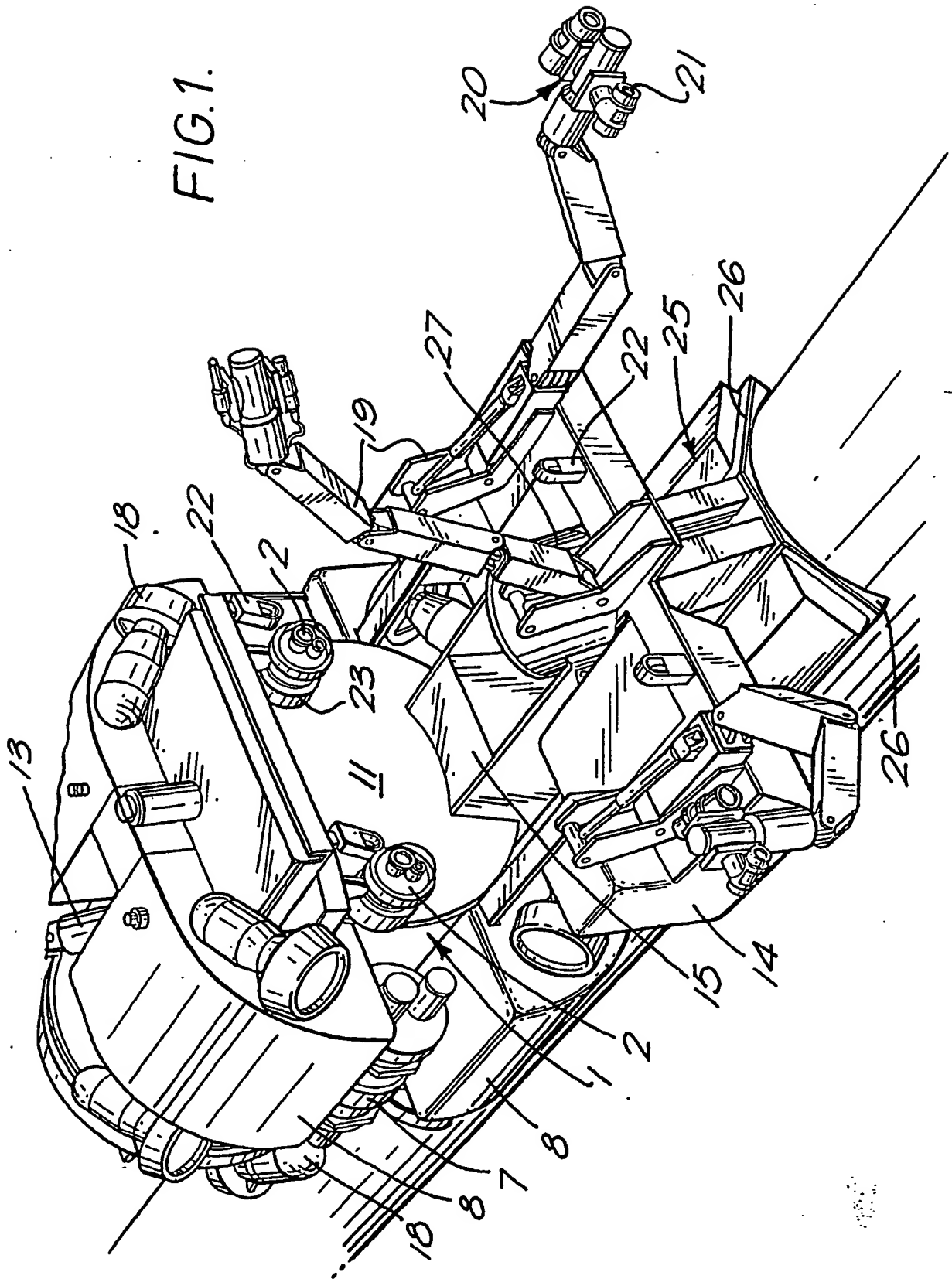
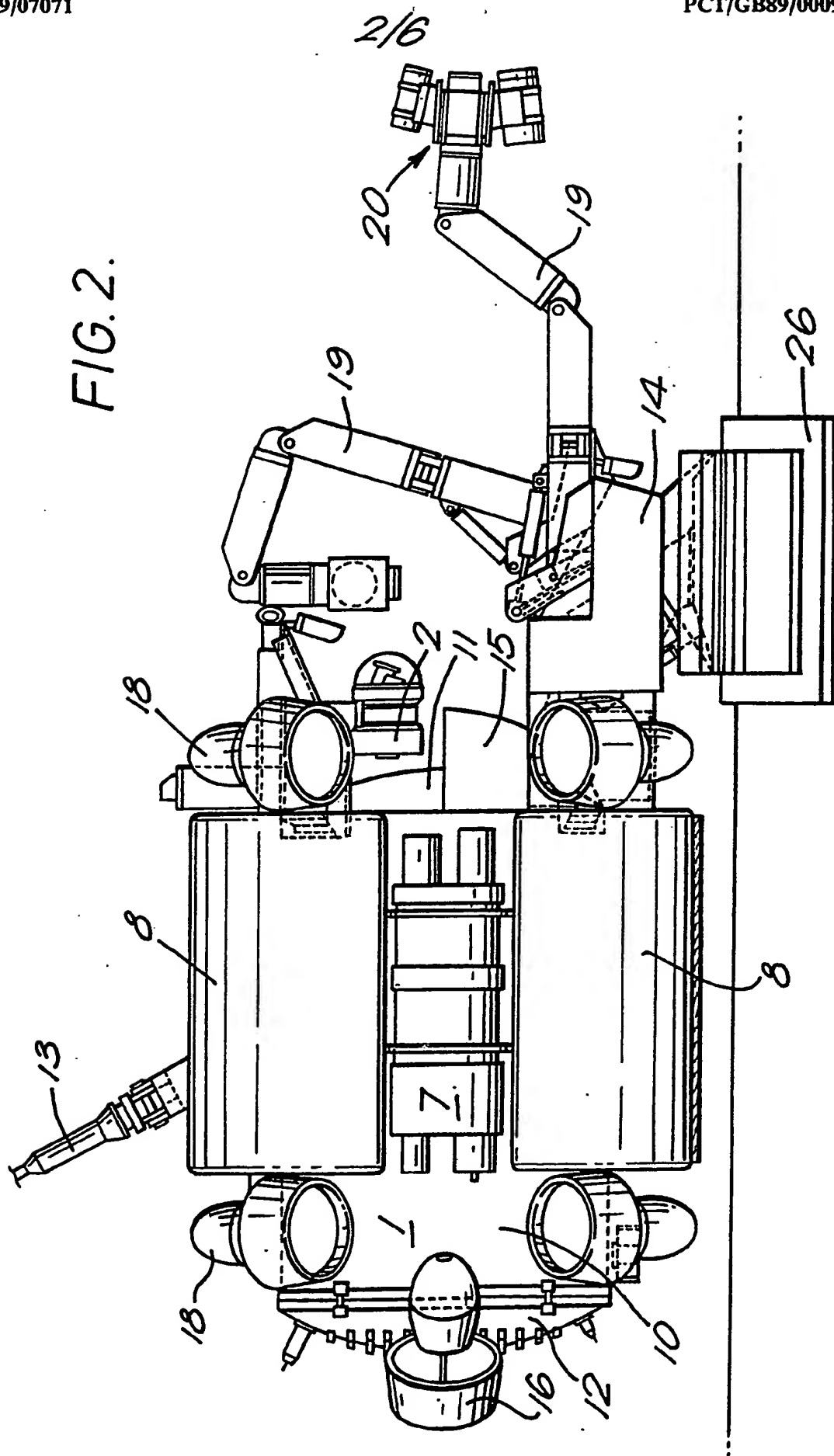


FIG. 2.



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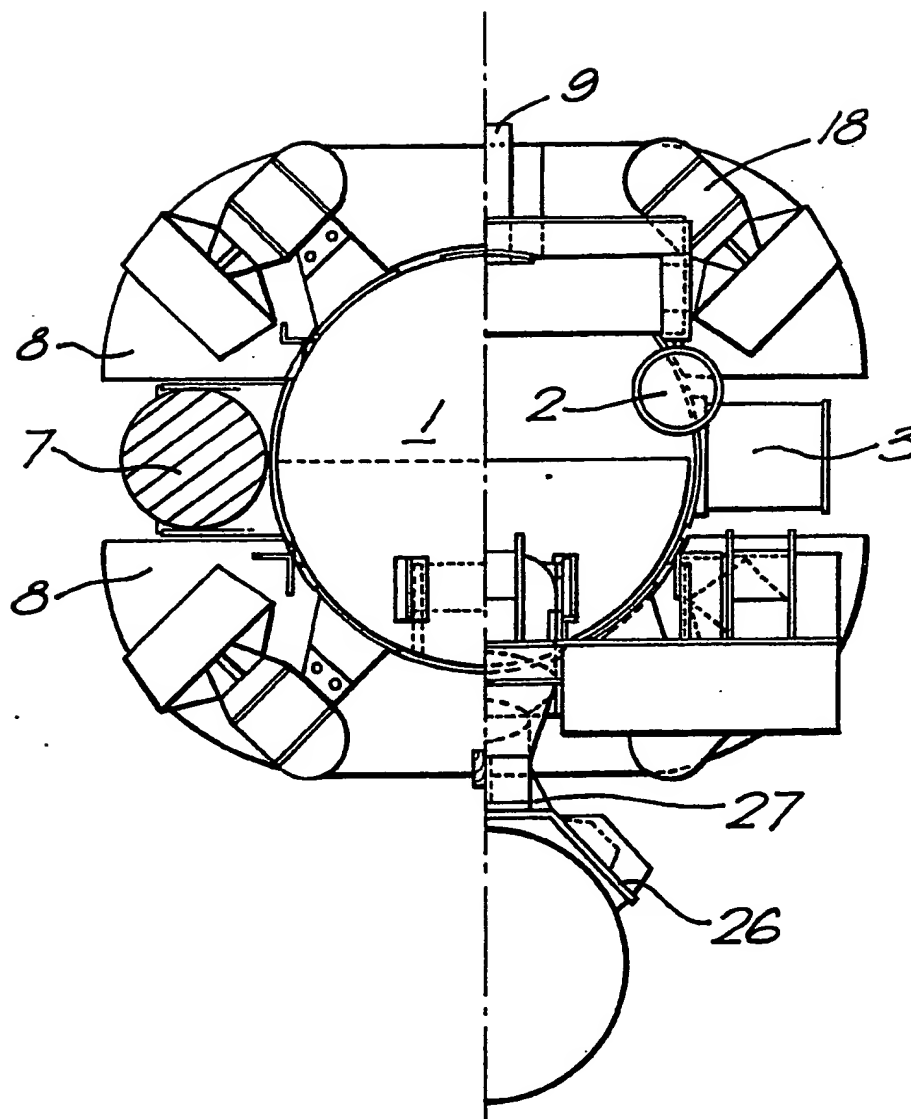


FIG. 3.

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FIG.4a.

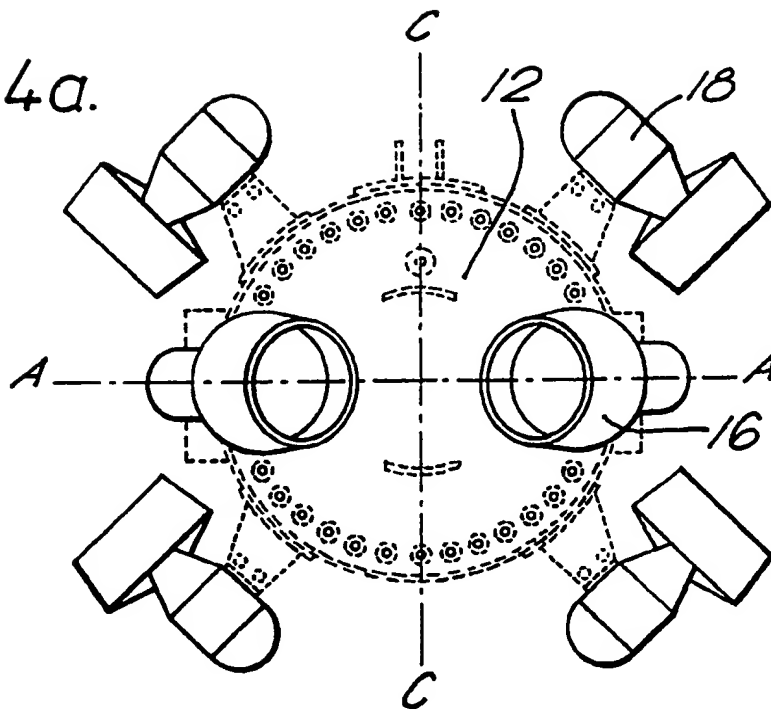


FIG.4b.

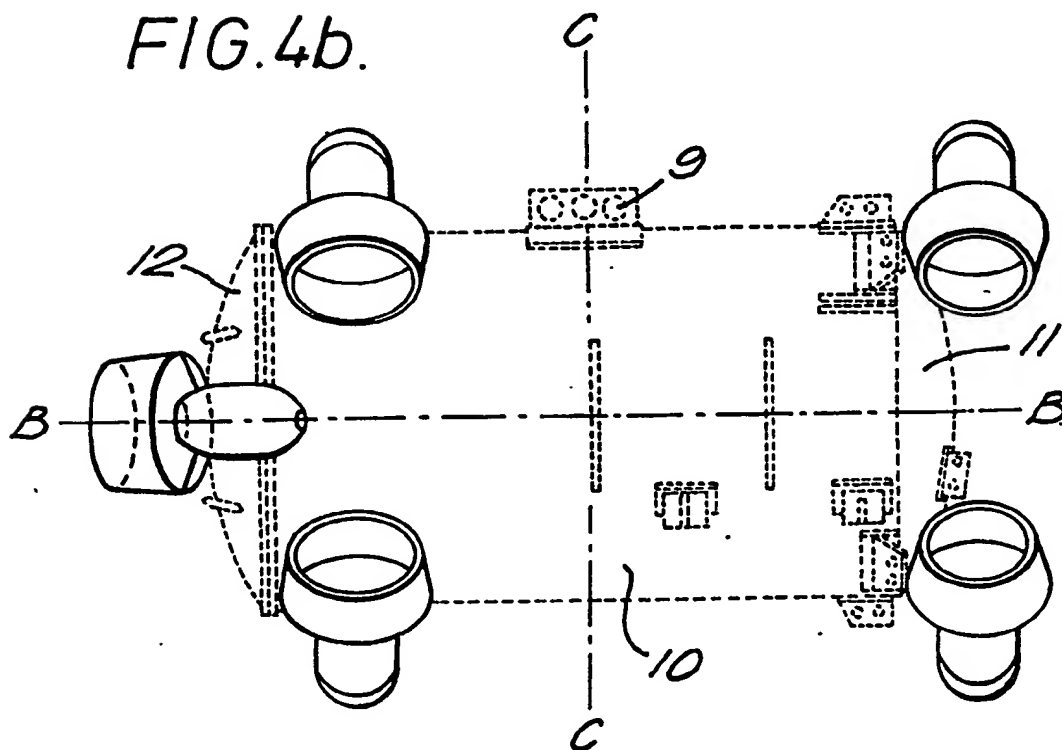
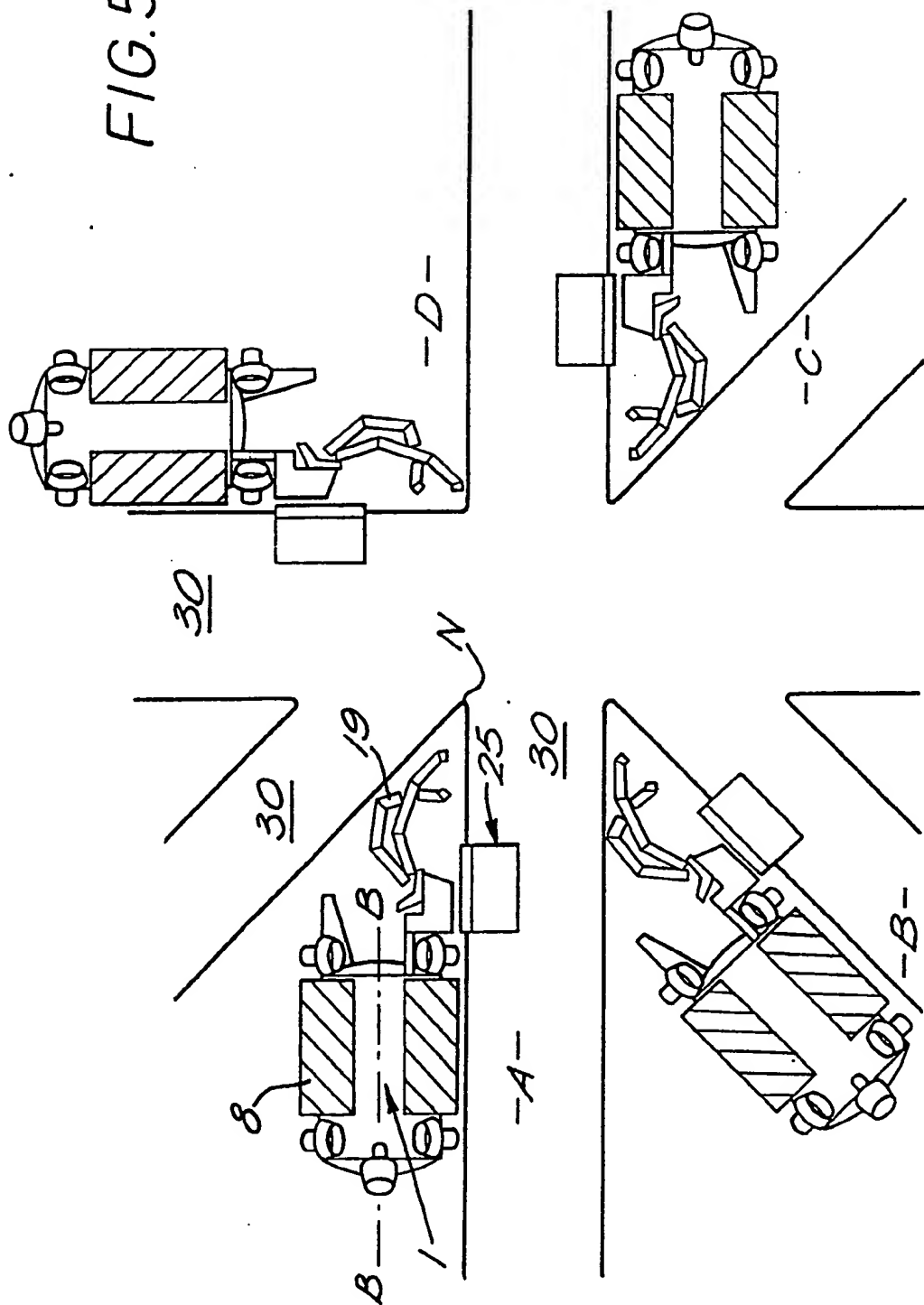


FIG. 5.



A subsea inspection vehicle which is intended to be remotely operated comprises a substantially cylindrical pressure vessel (1). A pair of generally arcuate buoyancy tanks (8) and external equipment (3, 7) are supported on the vessel (1) in a manner arranged such that the vessel remains substantially astable. A plurality of thrusters (16, 18) are carried by the vessel (1) and are arranged to enable movement of the vessel (1) relative to all six degrees of freedom provided by its astable configuration. The vessel can be moved in any direction at any attitude of pitch, roll or yaw and can thereby emulate the flexibility of movement of a diver.

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INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 89/00099

I. CLASSIFICATION OF SUBJECT MATTER (If several classification symbols apply, indicate all) ⁶ According to International Patent Classification (IPC) or to both National Classification and IPC		
IPC ⁴ : B 63 C 11/42		
II. FIELDS SEARCHED		
Minimum Documentation Searched ⁷		
Classification System	Classification Symbols	
IPC ⁴	B 63 C, B 63 G	
Documentation Searched other than Minimum Documentation to the extent that such Documents are included in the Fields Searched ⁸		
III. DOCUMENTS CONSIDERED TO BE RELEVANT ⁹		
Category ⁹	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
A	FR, A, 2583902 (DARD) 26th December 1986 see page 4 --	1,2,6,18, 19,25
A	IEEE Journal of Oceanic Engineering, volume OE-11, no. 3, July 1986, IEEE, (New York, US), D. Liddle: "Trojan: remotely operated vehicle", pages 364-372 --	1,6-8,14, 18-20,25
A	US, A, 3381485 (CROOKS et al.) 7 May 1968 see abstract; figure 2 --	1,6,18, 20,25
A	FR, A, 2128892 (COMPAGNIE FRANÇAISE DES PÉTROLES) 27 October 1972 see page 7; figure 1 -----	1
<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p>¹⁰ Special categories of cited documents: ¹⁰</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubt on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> </div> <div style="width: 45%;"> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"&" document member of the same patent family</p> </div> </div>		
IV. CERTIFICATION		
Date of the Actual Completion of the International Search		Date of Mailing of this International Search Report
14th June 1989		- 5 OCT 1989
International Searching Authority		Signature of Authorized Officer
EUROPEAN PATENT OFFICE		 T.K. WILLIS

FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

V. ☐ OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE ¹

This international search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1. ☐ Claim numbers....., because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claim numbers....., because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claim numbers....., because they are dependent claims and are not drafted in accordance with the second and third sentences of PCT Rule 6.4(a).

VI. ☒ OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING ²

This international Searching Authority found multiple inventions in this international application as follows:

"See Form PCT/ISA/206 dated 14-07-89"

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.
2. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:
3. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:
4. ☐ As all searchable claims could be searched without effort justifying an additional fee, the international Searching Authority did not invite payment of any additional fee.

Remark on Protest

- ☐ The additional search fees were accompanied by applicant's protest.
- ☐ No protest accompanied the payment of additional search fees.

**ANNEX TO THE INTERNATIONAL SEARCH REPORT
ON INTERNATIONAL PATENT APPLICATION NO.**

GB 8900099
SA 27147

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on 27/09/89
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
FR-A- 2583902	26-12-86	None	
US-A- 3381485		None	
FR-A- 2128892	27-10-72	CA-A- 984686	02-03-76
		GB-A- 1345683	30-01-74
		US-A- 3800722	02-04-74